RUNOFF AND SOIL EROSION EVALUATION BY THE ANNAGNPS MODEL IN A SMALL MEDITERRANEAN WATERSHED

F. Licciardello, D. A. Zema, S. M. Zimbone, R. L. Bingner

ABSTRACT. *In order to evaluate prediction models of runoff and sediment yield in a Mediterranean environment, the distributed parameter, physically based, continuous simulation, daily time step AnnAGNPS model was applied to an experimental watershed of mainly pasture in Sicily. Results from AnnAGNPS simulations were evaluated using 7-year data monitored at this watershed. The model showed satisfactory capability in simulating surface runoff at event, monthly, and annual scales after calibration. Peak flow predictions were generally good for low flow events and poorer for higher flow rates. A high model efficiency was achieved for the 24 suspended sediment yield events recorded during the entire period of observation after reducing the roughness coefficients for both rangeland and cropland areas. The overall results confirmed the applicability of the AnnAGNPS model to the experimental conditions.*

Keywords. *AnnAGNPS model, Peak flow, Sediment yield, Soil erosion, Surface runoff, Watershed modeling.*

Structural and non-structural measures to control negative impacts of runoff and erosion processes can be properly addressed through reliable prediction models. Although there has been considerable effort, additional work is needed to assess and improve the reliability of available prediction models in different environmental contexts.

The AnnAGNPS (Annualized Agricultural Non-Point Source) model (Geter and Theurer, 1998; Bingner and Theurer, 2001) is among the distributed models developed to evaluate the continuous hydrologic and water quality responses of watersheds. Many major hydrologic concepts of the single-event model AGNPS (Young et al., 1987), widely applied around the world (Haregeweyn and Yohannes, 2003; Hassen et al., 2004; Leòn et al., 2004), have been updated through the continuous simulation modeling of physical processes governing routing of water, sediment, and pollutants associated with runoff events (Baginska et al., 2003).

AnnAGNPS has been implemented to assess runoff water amount and quality as well as sediment yield in small to large watersheds under different environmental conditions. Assessments of model performance, frequently coupled with calibration/validation trials in monitored watersheds ranging from 32 ha to 2500 km^2, have recently been published. Suttles et al. (2003) achieved poor AnnAGNPS predictions of sediment and nutrient loads in a Georgia watershed, covered by both extensive forest and riparian conditions, probably due to the defective data input within the model as well as needed modifications to the model. Moderate accuracy in model simulation of phosphorous and nitrogen processes was also highlighted by model applications in two small watersheds located in the Mississippi Delta (Yuan et al., 2005) and in the Sydney region (Baginska et al., 2003). The capability of the model (coupled to the BATHTUB eutrophication reservoirs model) in simulating nutrients load variations in response to land use changes in a Kansas large reservoir was pointed out by Wang et al. (2005).

In AnnAGNPS applications to a small Mississippi watershed, Yuan et al. (2001, 2005) demonstrated that AnnAGNPS adequately predicted long-term monthly and annual runoff and sediment yield; predicted and observed runoff from individual events were reasonably close. In tests carried out by Baginska et al. (2003) in a small Australian watershed, mainly covered by farming and residential land uses, appreciable model predictions were assessed for runoff at event scale after the calibration of hydrological parameters. Shrestha et al. (2006) implemented AnnAGNPS at a small Nepalese watershed, mainly forested and cultivated, showing the need of calibration processes for satisfactory runoff predictions; despite the calibration process, peak flow and sediment yield evaluation resulted in a much lower accuracy.

With particular reference to the Mediterranean environment, tests of the single-event model AGNPS were carried out in Italy, where hydrological effects of different land uses in an alpine environment (Cazorzi and Dalla Fontana, 1996; Cazorzi, 1996; Lenzi and Di Luzio, 1997) as well as soil erosion in southern small watersheds characterized by ephemeral streams (Morgagni et al., 1993; Licciardello and Zimbone, 2002) were successfully predicted.

In order to support the aim of evaluating the applicability of AnnAGNPS in a semi-arid Mediterranean environment, this article reports the results of model performance assess-

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ment carried out using a 7-year database collected at a small watershed in Sicily.

Materials and Methods

Brief Description of AnnAGNPS

AnnAGNPS (Geter and Theurer, 1998; Bingner and Theurer, 2001) is a distributed parameter, physically based, continuous simulation, daily time step model, developed initially in 1998 through a partnering project between the USDA Agricultural Research Service (ARS) and the Natural Resources Conservation Service (NRCS). The model simulates runoff, sediment, nutrients, and pesticides leaving the land surface and shallow subsurface and transported through the channel system to the watershed outlet; output is available on a daily, monthly, and annual scale. Required inputs for model implementation (up to 100 unique parameters for runoff volume assessment and up to an additional 80 unique parameters for sediment yield prediction) include climate data, watershed physical information, as well as crop, non-crop, and irrigation management data.

Because of the continuous nature of AnnAGNPS, climate information, which includes daily precipitation, maximum and minimum temperatures, dewpoint temperatures, sky cover, and wind speed, is needed to simulate temporal weather variations. The spatial variability of soils, land use, topography, and climatic conditions is accounted for by dividing the watershed into user-specified homogeneous drainage areas. The basic components of the model include hydrology, sedimentation, and chemical transport.

The SCS curve number technique (USDA-SCS, 1972) is used within the AnnAGNPS hydrologic submodel to determine the surface runoff on the basis of a continuous soil moisture balance. AnnAGNPS only requires initial values of curve number (CN) for antecedent moisture condition (AMC) II, because the model updates the hydrologic soil conditions on the basis of the daily soil moisture balance and according to the crop cycle.

The peak flow is determined using the extended TR-55 method (Cronshey and Theurer, 1998), which modifies the original NCRS-TR-55 technology (USDA-NCRS, 1986). The tabular method of developing a unit hydrograph in the original TR-55 method was converted into a regression equation that is then used by the extended TR-55 method in calculating mathematically peak discharge based on the rainfall distribution type selected by the AnnAGNPS user.

The AnnAGNPS erosion component simulates storm events on a daily basis for sheet and rill erosion based on the RUSLE method (Revised Universal Soil Loss Equation, version 1.5; Renard et al., 1997). The HUSLE (Hydrogeomorphic Universal Soil Loss Equation; Theurer and Clarke, 1991) is used to simulate the total sediment volume delivered from the field to the channel after sediment deposition.

The sediment routing component simulates sheet and rill sediment deposition in five particle size classes (clay, silt, sand, and small and large aggregates) on the basis of density and fall velocity of the particles and then routes sediment separately through the channel network up to the watershed outlet as a function of sediment transport capacity (calculated by the Bagnold equation; Bagnold, 1966). A key assumption is that the aggregates break up into their primary particles once they enter the stream channel.

For the chemical component of the model, dissolved and adsorbed sediment predictions are assessed for each cell by a mass balance approach (Yuan et al., 2005). Algorithms for nutrient (nitrogen, phosphorous, and organic carbon) and pesticide dynamics are largely similar to the EPIC (Williams et al., 1984) and GLEAMS (Leonard et al., 1987) models. More details on the theoretical background of AnnAGNPS are reported by Bingner and Theurer (2005).

Characteristics of the Cannata Watershed

AnnAGNPS (version 3.52) was tested at the Cannata watershed, which is a mountainous tributary, ephemeral in flow, of the Flascio River in eastern Sicily (37° 53′ N, 14° 46′ E). The watershed covers about 1.3 km^2 between 903 m and 1270 m above mean sea level with an average land slope of 21%. The longest channel pathway is about 2.4 km, with an average slope of about 12%. The Kirpich concentration time (the time required for runoff to flow to the outlet from the point of a drainage basin having the longest travel time; Chow et al., 1988) is 0.29 h. The equipment includes (fig. 1): a meteorological station (A, located outside of the watershed) recording rainfall, air temperature, wind, solar radiation and pan evaporation; two pluviometric stations (B and C); and a hydrometrograph (D) connected to a runoff water automatic sampler (E) for the measurement of sediment concentration in the flow.

Considering that baseflow is not considered by AnnAGNPS, the surface runoff separation from baseflow was performed by the traditional manual linear method applied to observed stream flow data. Based on studies performed by Arnold et al. (1995) as well as Arnold and Allen (1999), these results match reasonably well with those obtained through an automated digital filter; the differences in the surface runoff component extracted by the two methods are up to 16.7% at yearly scale.

In a survey conducted at the start of experimental campaign, five different soil textures (clay, loam, loam-clay, loam-sand, and loam-sand-clay) were recognized; clay-loam (USDA classification) resulted as the dominant texture (63% cases of 57 topsoil samples). The soil saturated hydraulic conductivity, measured by a Guelph permeameter (Eijkelkamp model 2800; Reynolds and Elrick, 1985), resulted in the range 0.2 to 17.6 mm h^{-1} (n = 57; CV = 103%). Continuous monitoring of land use has highlighted the prevalence of pasture areas (ranging between 87% and 92% of the watershed area) with different vegetation complexes (up to 15 species) and ground covers. Four soil cover situations can be distinguished: a high-density herbaceous vegetation (eventually subjected to tillage operations), a medium-density herbaceous vegetation, sparse shrubs, and cultivated winter wheat with a wheat-fallow rotation. More detailed information about the watershed characteristics and the monitoring equipment were reported previously (Licciardello and Zimbone, 2002).

AnnAGNPS Implementation in the Cannata Watershed

The watershed discretization into homogeneous drainage areas ("cells") and the hydrographic network segmentation into channels ("reaches") were performed using the GIS in–

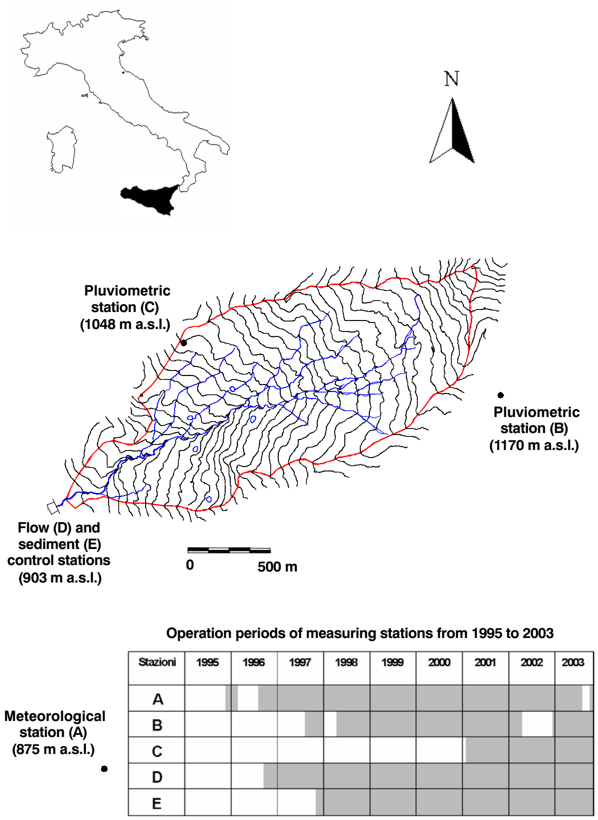

Figure 1. Location and operation periods of the equipments used for hydrometeorological monitoring of the Cannata watershed, Sicily.

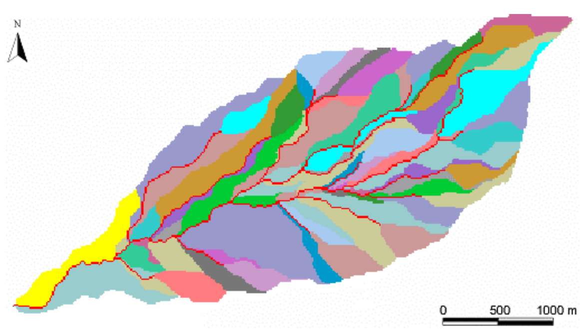

Figure 2. Layout of the Cannata watershed discretization.

terface incorporated into AnnAGNPS (fig. 2 and table 1). The geometry and the density of the drainage network were modeled by setting the critical source area to 1.25 ha and the minimum source channel length to 100 m, which allowed a suitable representation of the same watershed in a previous study (Licciardello et al., 2006). The elevation GIS layer was arranged by digitizing contour lines every 2 m on a 5-m resolution DEM; land use and soil input data were derived from 25-m resolution GIS maps. The morphologic parameters (i.e., cell slope length and steepness) as well as the dominant land uses and soil types were directly associated with each drainage area by means of the GIS interface.

Input daily climate data (maximum and minimum temperatures, solar radiation, and wind velocity) were surveyed at the meteorological station within the watershed. Daily rainfall input data were derived from records provided by the working rain gauges in the different periods (fig. 1) and input

Table 1. Characteristics of the GIS data layers of the Cannata watershed.

GIS Data Layer	Resolution
Digital Elevation Model (DEM)[a]	5 × 5 m
Land use map	25 × 25 m
Soil type map	78 drainage areas
Morphological discretization[b]	32 channels

[a] Arranged by digitizing the 2 m elevation contour lines.
[b] Obtained by setting the critical source area to 1.25 ha and the minimum source channel length to 100 m (Licciardello et al., 2006).

Table 2. Values or range of the RUSLE parameters set at the Cannata watershed, Sicily.

Parameter	Value or Range	Unit
R factor	1039.53	MJ mm ha^{-1} h^{-1} $year^{-1}$
10-year EI_{30}	762.75	MJ mm ha^{-1} h^{-1} $year^{-1}$
K factor	0.39 to 0.53	10^3 kg ha^{-1} per R-factor unit
LS factor	1.72 to 4.94	--
C factor		
Pasture[a]	0.016[b]; 0.029[c]	--
Cropland[d]	0.0002 to 0.042[b]; 0.0001 to 0.043[c]	--
P-factor	1	--

[a] Annual value for non-cropland (AnnAGNPS, 2001).
[b] Before calibration.
[c] After calibration and for validation.
[d] Series of twenty-four 15-day period values per year for cropland (AnnAGNPS, 2001).

to each drainage area by applying the Thiessen polygon method (Thiessen, 1911), except when only the rainfall recorded at a single station was available (fig. 1). Meteorological and pluviometric input data were properly arranged by the AnnGNPS weather subroutines.

To allow the model to adjust the initial soil water storage terms, the first two years (Sept. 1996 to Aug. 1998) were appended to the beginning of the precipitation and meteorological data set (Sept. 1996 for both) used for the Cannata watershed; yearly rainfall amounts were close to the maximum (for the first year) and the average (for the second year) values.

The initial values of CN, unique throughout the whole simulation period, were initially derived from the standard procedure set by the USDA Soil Conservation Service (USDA-SCS, 1972). Management information (crop types and rotation as well as agricultural operations) were set following the RUSLE guidelines and database.

Table 2 shows the values or range of the RUSLE parameters set for the Cannata watershed. The average annual rainfall factor (R), its cumulative percentages for 24 series of 15-day periods in a year, and the soil erodibility factor (K) were determined according to the Wischmeier and Smith (1978) guidelines, the latter on the basis of a field survey of soil hydrological characteristics (Indelicato, 1997). For each texture, a uniform soil profile was modeled up to 1500 mm by averaging the required physical characteristics from the field samples. The C factor was directly calculated by the model as an annual value for non-cropland and as a series of twenty-four 15-day values per year for cropland (based on prior land use), surface cover, superficial roughness, and soil moisture condition (AnnAGNPS, 2001; Bingner and Theurer, 2005). The P factor was always set to 1, due to the absence

Table 3. Input parameters subject to calibration process of AnnAGNPS model at the Cannata watershed, Sicily.

Parameter	Land Use	Values: Default	Values: After Calibration
Hydrological submodel			
Initial curve number (CN)	Pasture	79[a]; 84[b]	72[a]; 78[b]
	Cropland	81[a]; 84[b]	75[a]; 78[b]
Synthetic 24 h rainfall distribution type	--	I	Ia
Erosive submodel			
Sheet and conc. flow Manning's roughness coefficient ($m^{-1/3}$ s)	Pasture	0.13[c]	0.1
	Cropland	0.125[c]	0.1
Surface long-term random roughness coefficient (mm)	Pasture + cropland	32	15

[a] Soil hydrological group C.
[b] Soil hydrological group D.
[c] According to the indications in the AGNPS user manual (Young et al., 1994) integrated with those provided by the user manual of the EUROSEM model (Morgan et al., 1998).

of significant protection measures in the watershed.

Model Evaluation Procedure

Both the hydrological and erosion components of AnnAGNPS were calibrated/validated in logical order according to the input dependencies on each other and taking into account the most sensitive inputs. The split-sample technique (Klemes, 1986) was used to evaluate the model in terms of runoff volume, peak flow, and sediment yield.

Following the usual approach to continuous model evaluations (Neitsch et al., 2002), the runoff volume was assessed at the annual, monthly, and event scale. The calibration/validation process was carried out by modifying the initial values of CN, which represent a key factor in obtaining accurate prediction of runoff and sediment yield (Yuan et al., 2001; Shrestha et al., 2006) and the most important input parameter to which the runoff is sensitive (Yuan et al., 2001; Baginska et al., 2003), besides soil (field capacity, wilting point, and saturated hydraulic conductivity) as well as climate parameters (precipitation, temperature, and interception).

In order to calibrate/validate the peak flows and the sediment yields, both 24 h rainfall distributions typical of a Pacific maritime climate (types I and Ia) with wet winter and dry summers (USDA-NCRS, 1986) derived by the extended TR-55 method database were used.

The sediment yields were evaluated at event scale by adjusting the surface long-term random roughness coefficient (which affects the RUSLE C factor) as well as the sheet and concentrated flow Manning's roughness coefficients (table 3).

Model Performance Assessment

Model performance was evaluated by qualitative and quantitative approaches. The qualitative procedure consisted of visually comparing in data-display graphics of the observed and simulated values. The different components of the model were quantitatively evaluated at different time scales by the coefficient of determination (r^2) as well as a combination of both summary and difference measures (table 4), as suggested in many works (Willmott, 1982; Legates and McCabe, 1999; Krause et al., 2005).

Table 4. Coefficients and difference measures for model evaluation and their range of variability.

Coefficient or Measure	Equation	Range of Variability
Coefficient of determination	$r^2 = \left[\frac{\sum_{i=1}^{n} (O_i - \overline{O})(P_i - \overline{P})}{\sqrt{\sum_{i=1}^{n} (O_i - \overline{O})^2} \sqrt{\sum_{i=1}^{n} (P_i - \overline{P})^2}} \right]^2$	0 to 1
Coefficient of efficiency (Nash and Sutcliffe, 1970)	$E = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - \overline{O})^2}$	$-\infty$ to 1
Modified coefficient of efficiency (Willmott, 1982)	$E_1 = 1 - \frac{\sum_{i=1}^{n} \lvert O_i - P_i \rvert}{\sum_{i=1}^{n} \lvert O_i - \overline{O} \rvert}$	$-\infty$ to 1
Root mean square error	$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (P_i - O_i)^2}{n}}$	0 to ∞
Systematic RMSE (Willmott, 1982)	$\mathrm{RMSE}_s = \sqrt{\frac{\sum_{i=1}^{n} (\hat{P}_i - O_i)^2}{n}}$	0 to ∞
Unsystematic RMSE (Willmott, 1982)	$\mathrm{RMSE}_u = \sqrt{\frac{\sum_{i=1}^{n} (P_i - \hat{P}_i)^2}{n}}$	0 to ∞
Coefficient of residual mass (Loague and Green, 1991; Chanasyk et al., 2003)	$\mathrm{CRM} = \frac{\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} P_i}{\sum_{i=1}^{n} O_i}$	$-\infty$ to ∞

n = number of observations.
O_i, P_i = observed and predicted values at the time step i.
$\overline{O}$ = mean of observed values.
$\hat{P}_i$ = value predicted by the regression equation at the time step i.

The summary measures utilized were the mean and standard deviation of both observed and simulated values. Given that r^2, describing how much of the observed dispersion is explained by the prediction, is an insufficient and often misleading evaluation criterion, the Nash and Sutcliffe (1970) coefficient of efficiency (E) and its modified form (E_1) were used to assess model efficiency (table 4). In particular, E is more sensitive to extreme values, while E_1 is better suited to significant over- or underprediction by reducing the effect of squared terms (Legates and McCabe, 1999; Krause et al, 2005). As suggested by the same authors, E and E_1 were integrated with the root mean square error (RMSE), which describes the difference between the observed values and the model predictions in the unit of the variable. In addition, following Willmott (1982), the "systematic" and "unsystematic" portions of RMSE were quantified. For a "good" model, the systematic error (RMSE_s) approaches zero, while the unsystematic difference (RMSE_u) is close to the RMSE. Moreover, the coefficient of residual mass (CRM) was used to indicate a prevalent model over- or underestimation of the observed values (Loague and Green, 1991; Chanasyk et al., 2003).

The values considered to be optimal for these criteria were 1 for r^2, E, and E_1 and 0 for RMSE and CRM (table 4). In particular, the value of 1 for the coefficient of determination means that the dispersion of the prediction is equal to that of the observation. Moreover, according to common practice (Van Liew and Garbrecht, 2003), simulation results are considered good for values of E greater than or equal to 0.75, satisfactory for values of E between 0.75 and 0.36, and unsatisfactory for values below 0.36.

Results and Discussion

Hydrological Observations

In the observation period of 1996 to 2003, yearly rainfall between 541 and 846 mm (mainly concentrated from September to March) was recorded at the station A, with a mean and standard deviation (SD) of 662 and 134 mm, respectively. The corresponding yearly runoff was in the range 30.7 to 366 mm, with a mean of 105 mm and SD of 100 mm. The coefficient of yearly runoff, calculated as the ratio between total runoff and total rainfall as recorded by station A, varied between 5% and 41%, with a mean and SD of 15% and 75%, respectively. The analysis of a four-event sample provided a flash response with a time lag in the range 41.0 to 84.2 min. Occasional high differences in recorded rainfall events between the three gauges were found; as expected, rainfall spatial variability decreased on a monthly and yearly basis.

At event scale, rainfall depths over 6.8 mm gave runoff volumes higher than 1 mm; the maximum runoff volume and discharge recorded in the observation period were 159.6 mm and 3.4 $m^3\ s^{-1}$ (2.6 $L\ s^{-1}\ km^{-2}$), respectively. Twenty-four erosive events were sampled with a suspended sediment concentration between 0.1 and 9.2 $g\ L^{-1}$; the maximum event sediment yield (estimated on the basis of runoff volume and suspended sediment concentration in the flow) was 283 × 10^3 kg (2168.4 $kg\ ha^{-1}$).

Calibration Test

The observed runoff volumes from October 1996 to December 2000 at the watershed outlet were used for model calibration at monthly and event scales; annual model performance was evaluated by utilizing observations from the year 1997 to 2000. In trying to approximate the mean and SD values of the observed runoff, the initial CNs were properly decreased both in rangeland and in cropland areas (table 5). Table 5 shows the values of the chosen difference measures obtained for runoff at annual, monthly, and event scales before and after calibration.

The simulated total runoff volume for the period of October 1996 to December 2000 (405.72 mm) was only slightly higher than the observed value (393.23 mm), showing a runoff prediction capability for long periods, which was also detected by other authors (Yuan et al., 2001). The improvement in the annual runoff volume predictions after the calibration is due to the reduction of the cumulated volume overprediction relative to events with smaller runoff (fig. 3). In some cases, at the beginning of the wet season, runoff was generated by AnnAGNPS but not observed (fig. 4). This was probably due to the peculiarity of the hydrological processes governing runoff formation in Mediterranean regions, depending not only on catchment characteristics but also on antecedent hydrological conditions and characteristics of the rainfall events, with low runoff coefficients as a result of short-duration, high-intensity convective storms over dry soils (Latron et al., 2003).

Table 5. Values of the coefficients, summary, and difference measures applied to runoff volumes at different time scales for calibration and validation tests at the Cannata watershed, Sicily.

	Mean (mm)	SD (mm)	r^2	E	E_1	RMSE (mm)	$RMSE_s$ (mm)	$RMSE_u$ (mm)	CRM
Calibration test									
Annual scale (1997 to 2000)									
Observed	78.54	40.25	--	--	--	--	--	--	--
Simulated[a]	107.05	43.05	0.59	−0.13	−0.10	38.19	32.35	24.79	−0.40
Simulated[b]	77.17	39.81	0.72	0.70	0.53	6.30	18.96	19.84	0
Monthly scale (Oct. 1996 to Dec. 2000)									
Observed	7.71	15.91	--	--	--	--	--	--	--
Simulated[a]	10.79	19.50	0.75	0.59	0.48	10.15	3.23	9.62	−0.40
Simulated[b]	7.70	15.98	0.78	0.77	0.61	7.61	1.77	7.40	0
Event scale (Oct. 1996 to Dec. 2000)									
Observed	0.25	2.42	--	--	--	--	--	--	--
Simulated[a]	0.36	2.79	0.83	0.76	0.52	1.18	0.15	1.17	−0.40
Simulated[b]	0.25	2.36	0.85	0.84	0.64	0.96	0.25	0.92	0
Validation test									
Annual scale (Jan. 2001 to Dec. 2003)									
Observed	158.74	145.05	--	--	--	--	--	--	--
Simulated[b]	108.38	80.79	0.99	0.62	0.54	72.74	72.72	1.46	0.32
Monthly scale (Jan. 2001 to Dec. 2003)									
Observed	13.23	34.43	--	--	--	--	--	--	--
Simulated[b]	9.03	24.20	0.93	0.85	0.66	13.27	11.70	6.26	0.32
Event scale (Jan. 2001 to Dec. 2003)									
Observed	0.43	5.37	--	--	--	--	--	--	--
Simulated[b]	0.30	4.00	0.87	0.83	0.58	2.21	1.65	1.46	0.32

[a] Default simulation.
[b] Calibrated model.

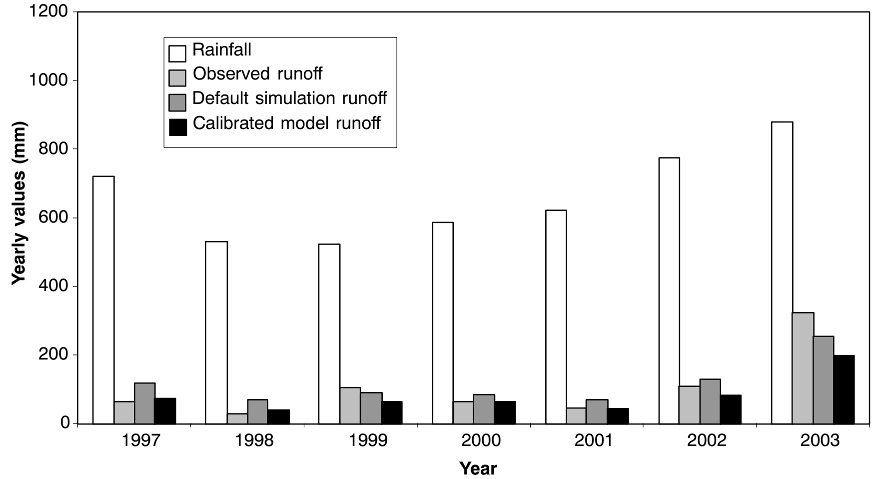

Figure 3. Comparison between observed and simulated (using default and calibrated parameters) yearly runoff volume for the years 1997 to 2003 at the Cannata watershed, Sicily.

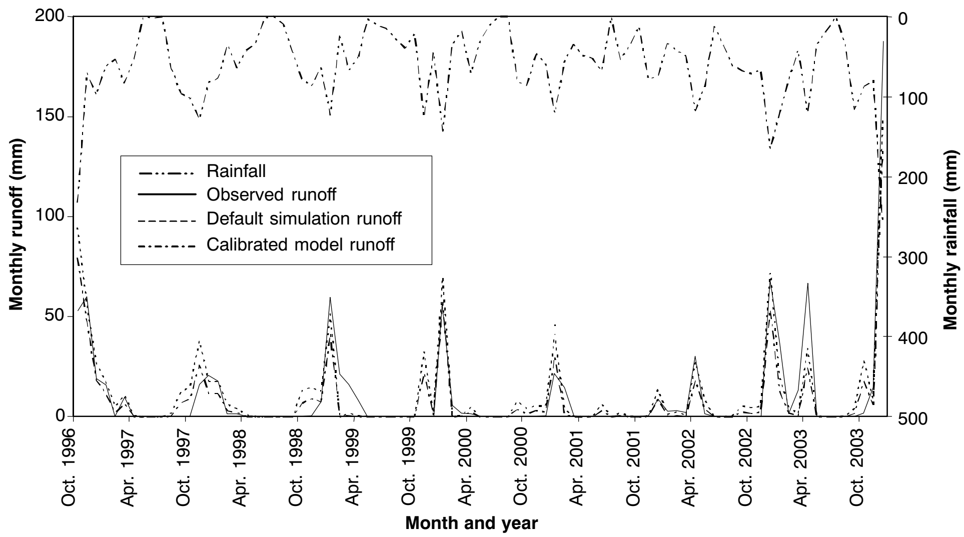

Figure 4. Comparison between observed and simulated (using default and calibrated parameters) monthly runoff volume for the whole period at the Cannata watershed, Sicily.

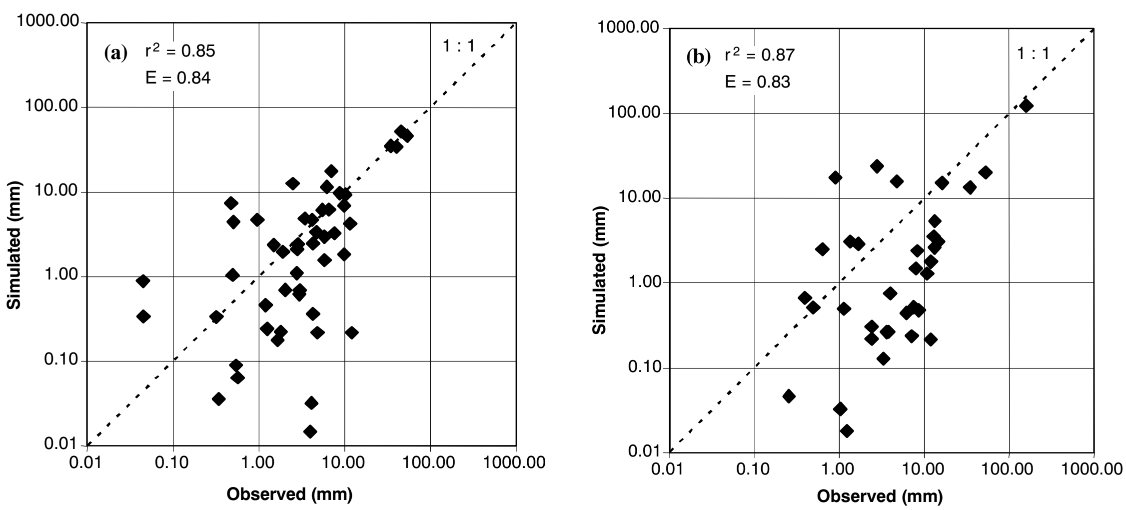

Figure 5. Comparison between observed and simulated runoff at event scale for (a) calibration and (b) validation tests at the Cannata watershed, Sicily.

Table 6. Values of the coefficients, summary, and difference measures applied to peak flow at event scale for calibration and validation tests at the Cannata watershed, Sicily.

	Mean ($m^3 s^{-1}$)	SD ($m^3 s^{-1}$)	r^2	E	E_1	RMSE ($m^3 s^{-1}$)	$RMSE_s$ ($m^3 s^{-1}$)	$RMSE_u$ ($m^3 s^{-1}$)	CRM
Calibration test (Oct. 1996 to Dec. 2000)									
Observed	0.02	0.11	--	--	--	--	--	--	--
Simulated[a]	0.03	0.33	0.57	−4.04	0.05	0.26	0.14	0.22	−1.12
Simulated[b]	0.01	0.14	0.56	0.34	0.52	0.09	0.01	0.09	0.14
Validation test (Jan. 2001 to Dec. 2003)									
Observed	0.02	0.14	--	--	--	--	--	--	--
Simulated[b]	0.02	0.23	0.66	0.05	0.51	0.14	0.04	0.13	0.11

[a] Default simulation.
[b] Calibrated model.

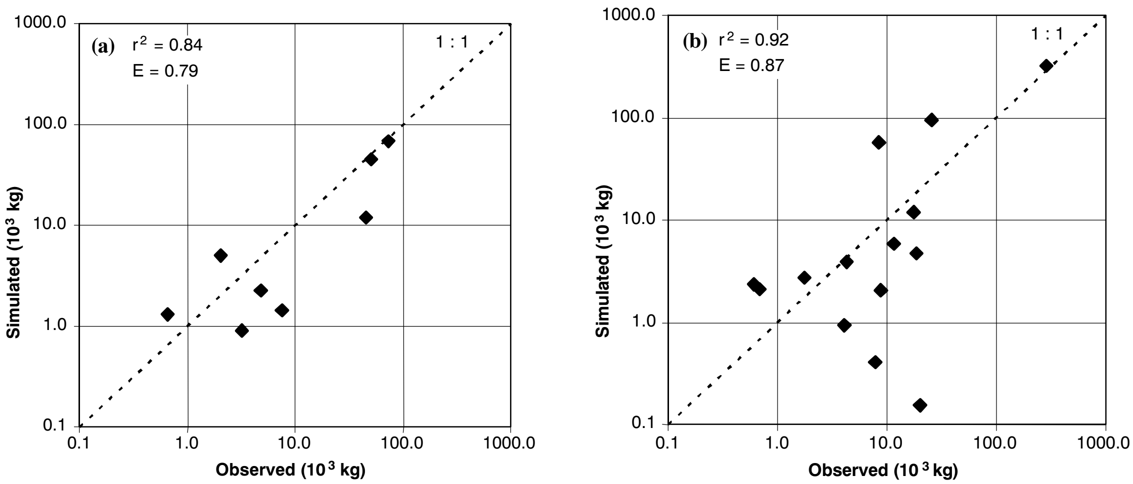

Figure 6. Comparison between observed and simulated sediment yield at event scale for (a) calibration and (b) validation tests at the Cannata watershed, Sicily.

The goodness of fit between observed and simulated runoff volumes (fig. 5) was also confirmed at the event scale by the summary measures as well as by the satisfactory values of E_1 and the low RMSE and CRM (table 5). A similar value of E was found in the model calibration test carried out by Baginska et al. (2003).

The apparent best results achieved for monthly and event-scale runoff volume predictions with respect to annual values may depend on the fact that the simulation period only represents a few years of data (four years and three years for the calibration and validation periods, respectively), while monthly and event-scale simulations provide more data for the statistics. Moreover, in table 5, results of simulations related to the period of October to December 1996, which was very well simulated by the model, are not reported.

As expected, the coefficient E_1 is less sensitive to peaks (Krause et al., 2005) and was generally lower than E, but nevertheless satisfactory after the calibration process. RMSE was limited to its unsystematic part at every time scale, indicating the good model performance (Willmott, 1982).

Adjustments of minimum and maximum interception evaporation (the portion of precipitation that neither runs off nor infiltrates) within the lower and upper default bounds assumed by AnnAGNPS for daily pluviometric and meteorological data did not improve the model prediction capability.

Peak flow predictions were closer to the observed values when the type Ia synthetic 24 h rainfall distribution (less intense than type I) was used. The overall model performance was satisfactory for less intense events, as shown by the E_1 coefficient (table 6).

High values of the coefficient of determination and model efficiency (E and E_1) were found for the suspended sediment yield events observed from October 1996 to December 2000 (fig. 6) when the AnnAGNPS erosive submodel was calibrated (table 7). By decreasing the surface long-term random roughness coefficient as well as the sheet and concentrated flow Manning's roughness coefficients for both rangeland and cropland areas, the tendency to underprediction was substantially reduced. The model response was remarkably more sensitive to the random roughness (more than 95% of the model efficiency improvement) than the Manning's coefficients adjustments (table 3).

Peak flow and sediment yield predictions were only slightly sensitive to the calibration of the hydrological submodel; the model efficiency in sediment yield prediction did not increase by adjusting either the Manning's roughness coefficient for channels or the ratio of rill to inter-rill erosion for bare soil.

Validation Test

The performance of the calibrated model was evaluated for the period of January 2001 to December 2003 in terms of runoff, peak flow, and sediment yield.

AnnAGNPS runoff volume predictions confirmed the satisfactory model performance both at the event and annual scales and the good performance at the monthly aggregated values (table 5). However, an underprediction was highlighted by the difference in summary measures and the values of RMSE (its systematic part is, in this case, not negligible as in the calibration test) and CRM. This tendency was mainly

Table 7. Values of the coefficients, summary, and difference measures applied to sediment yield at event scale for calibration and validation tests at the Cannata watershed, Sicily.

	Mean (10^3 kg)	SD (10^3 kg)	r^2	E	E_1	RMSE (10^3 kg)	$RMSE_s$ (10^3 kg)	$RMSE_u$ (10^3 kg)	CRM
Calibration test (Oct. 1996 to Dec. 2000)									
Observed	23.31	28.30	--	--	--	--	--	--	--
Simulated[a]	11.00	16.46	0.84	0.51	0.49	18.52	17.46	6.19	0.53
Simulated[b]	17.16	25.74	0.84	0.79	0.71	12.27	7.58	9.65	0.26
Validation test (Jan. 2001 to Dec. 2003)									
Observed	26.17	69.13	--	--	--	--	--	--	--
Simulated[b]	32.14	81.62	0.92	0.87	0.55	24.34	10.83	21.79	–0.23

[a] Default simulation.
[b] Calibrated model.

due to underestimation of the more significant events (fig. 5), as also found in the tests performed by Yuan et al. (2001).

The poor performance of the model in predicting extreme peak flows was confirmed in the validation period. The overall model prediction capability was unsatisfactory (table 6), as shown by the poor value of the coefficient of efficiency (E = 0.05). A high overprediction (over 105%) for the most significant event, which occurred on 12 December 2003, is also noted.

A satisfactory model efficiency (E_1 = 0.55) and a very high coefficient of determination (r^2 > 0.90) were also found for the suspended sediment yield events observed in the period of 2001 to 2003 (table 7 and fig. 6). The satisfactory value achieved for the Nash and Sutcliffe coefficient (E = 0.87) was mainly due to the successful performance of the model for large rainfall events, in particular for the highest sediment yield, which occurred on 12 December 2003.

Conclusions

Surface runoff volume, peak flow, and sediment yield AnnAGNPS predictions were evaluated using observations at the Cannata watershed in Sicily from October 1996 to December 2003. After a reduction of the initial CNs for both rangeland and cropland areas, the model showed a satisfactory capability in simulating surface runoff at annual scale, and good model performance was achieved at monthly and event scales. This indicates that the SCS curve number method is suitable for runoff predictions in the experimental conditions. However, even after the calibration/validation processes, the model tendency to overpredict smaller events and underpredict larger events persisted.

Peak flow model predictions were satisfactory for less intense storm events, but poorer for larger events, as also highlighted by Shrestha et al. (2006). Improvements in the rainfall distribution database utilized in the simulations would improve the model's performance.

High values of the coefficient of determination and model efficiency were found for the 24 suspended sediment yield events recorded during the whole period of observation after reducing the surface long-term random roughness coefficient as well as Manning's roughness coefficients for both rangeland and cropland areas. The HUSLE method was successful in predicting the sediment yield observed events of higher magnitude (>10 × 10^3 kg) better than smaller events. This behavior may depend on the fact that RUSLE is meant to be used for long-term estimates. For this reason, comparison of individual events may not agree as well as long-term annual values (Yuan et al., 2001; Shrestha et al., 2006).

As pointed out in the tests carried out in the experimental conditions, AnnAGNPS may be considered suitable to simulate significant sediment yield events. Further improvements in the hydrological submodel and in the erosion component could result in a higher reliability in the model predictions.

The overall results so far achieved encourage the efforts aiming to support the transferability of AnnAGNPS model in the Mediterranean environment as a practical tool in approaching erosion problems and land use planning.

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